# *synroc*ANSTO*

# Low-Risk Waste Forms to Lock up Nuclear Waste

* The Australian Nuclear Science & Technology Organisation (ANSTO) is Australia's national nuclear laboratory.

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# Challenges & Drivers

## HLW Wastes

**Multiple legacy sites & sources**

- ✓ 94M gals of diverse HLW at multiple sites
- ✓ Estimated $105B costs, 70 years to clean up
- ✓ DOE targeting savings $29B, 20-35 years goal
- ✓ Vitrification in borosilicate glass is baseline

***Problematic Wastes → Alternative disposal matrices***

## Waste Forms

**Ceramics & Glass-Ceramics**

- ✓ Problematic wastes: opportunities for lower-cost, reduced risk, immobilization alternates to baseline
- ✓ Waste form must maximize loading, optimize durability and reduce emissions
- ✓ Provides defense-in-depth waste form options for HLW

***Alternative matrices → tailored for problematic wastes***

## Process

**Engineering**

- ✓ Accelerated cleanup schedule can't be achieved with current technology
- ✓ Complementary proven technologies include: sintering, hot-isostatic pressing (HIP), cold-crucible induction melting (CCIM)

***Integrated process solutions using mature technologies***

## Trends and Drivers

- ✓Reduced life cycle and life cycle costs
- ✓Reduced risk
- ✓Reduced facility legacy processing & disposal costs
- ✓Alternates must deliver ROI and be compatible with, existing processing plants
- ✓Safer, lower cost, faster solutions reqd
- ✓Mature technology

**Low-Risk Nuclear Waste Forms**

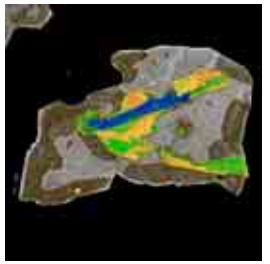
# *synroc*ANSTO's Approach

Deliver low-risk, reduced cost waste forms to lock up problematic HLW, via:

- Tailored high-performance waste form matrices
- Integrated process technologies

Designed to suit the unique characteristics of the waste

*synroc (synthetic rock) - Waste forms built on natural minerals that have demonstrated their survival over geological timeframes*



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# The importance of the waste form

The waste form:

- Determines waste loading and ultimately disposal efficiency
  - ↑ *cost savings via* ↑ *waste loadings &* ↓ *disposal canisters*
- Defines radionuclide release to the repository
  - ↓ *environmental risk via* ↑ *durability*
- Impacts off-gas emissions
  - ↓ *environmental risk via* ↓ *emissions*

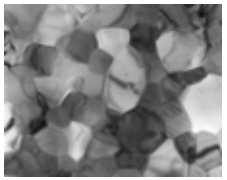
*The key to lowering the risk and reducing the cost of the cleanup campaign is getting the waste form selection right*

# *synroc*ANSTO Design Strategy

- Maximize waste loading to increase cost savings
  - *by utilizing waste components to advantage via 25 years experience in WF design*
- Optimize durability to lower environmental risk
  - *by incorporating waste in very durable mineral analog phases & high durability glasses*
- Increase flexibility to accommodate process and waste variations
  - *via in built chemical buffering*
- Integrate optimal consolidation technology
  - *process should place minimal constraints on the chemistry of the waste form and reduce or eliminate off-gas emissions*

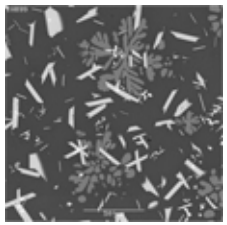
*Integrated waste form and process technology to achieve maximum benefits*

# *synroc*ANSTO Design Options



Multiphase ceramic

*(titanates, zirconates, phosphates & silicates)*



Glass-ceramic

*(durable glass plus ceramic phases)*


Process consolidation options:

*(sintering, hot-isostatic pressing & cold-crucible melting)*

*… determined by waste characteristics*

# *synroc*ANSTO Advantage

Lower cost and lower risk through enhanced performance:

- ✓ tailored alternative waste forms may introduce cost and schedule savings worth billions of dollars across the DOE sites
- ✓ integration of existing industry-proven processing technologies with *synroc*ANSTO's waste form design chemistry can increase waste loadings by 10 to over 40% compared to borosilicate glass
- ✓ can be achieved for problematic waste streams without loss of chemical durability, whilst reducing or eliminating off-gas emissions

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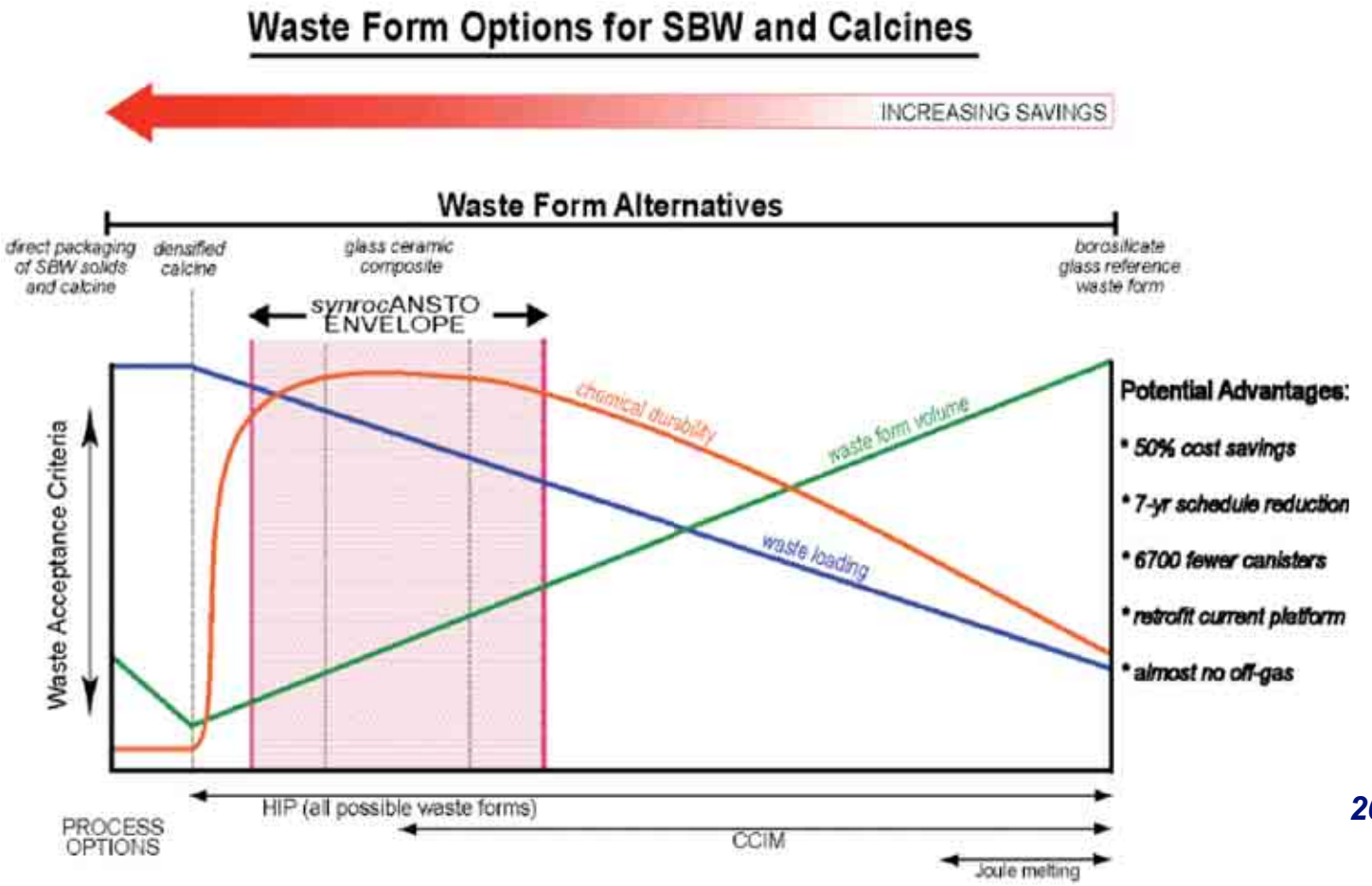
# INL-ANSTO White Paper*




*2004*

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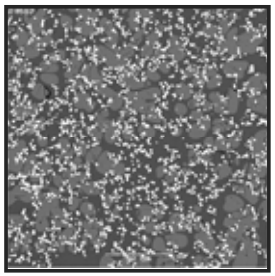
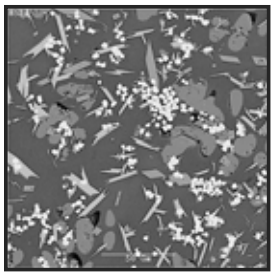
# *CS: INL HLW Calcines*

## HLW calcines - 98% of total radioactivity

| | | | |
|---|---|---|---|
| Consolidation: | HIP | CCIM | JHM |
| Matrix: | glass-ceramic | glass-ceramic | borosilicate glass |
| Waste loading: | **60-90%** | **50-60%** | **20-35%** |
| Durability (PCT-B): | 10-100 x EA glass | 10-100 x EA glass | 10 x EA glass |
| Final volume: (relative to untreated calcine) | 15-45% reduction | 10-15% reduction | 100+% increase |
| Temp: | 1300°C | 1300°C | 1150°C |
| Pressure: | 100 MPa | - | - |
| Off-gas: | very low | medium-high | medium-high |





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| Waste loading: | **60-90%** | **50-60%** | **20-35%** |
| % change in final waste form volume: (relative to untreated calcine) | 15-45% reduction | 10-15% reduction | 100+% increase |
| Disposal costs: | $1.20 billion | $1.44 billion | $2.4 billion |
| Facility D&C: | $600M (retrofit) | $660M (retrofit) | $1.3 billion (new) |
| D&D (includes secondary wastes) | $225M | $525M | $775M |
| TOTAL: | $2.03 billion | $2.63billion | $4.48 billion |
| **Savings:** | **$2.45 billion** | **$1.85 billion** | **-** |
| **% savings** | **55%** | **41%** | **-** |

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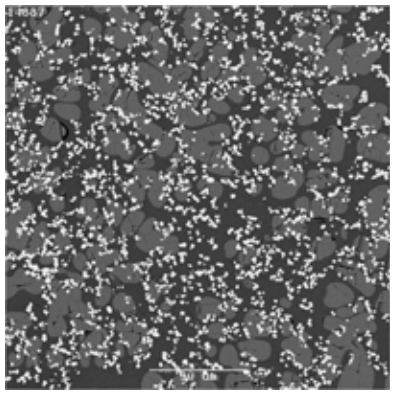
# *CS: Zr-rich INL calcine (BS#4)*

Consolidation: HIP
Scale: 30 Kg (65 lbs)
Diameter 20 cm (8 inch)
Waste loading: **80%**
Durability: 100 x EA Glass
Density: 3.10 g/cm$^3$
Final Volume: 35% reduction
(relative to untreated calcine)

<u>Crystalline phases:</u>
zirconia (major),
fluorite (major)



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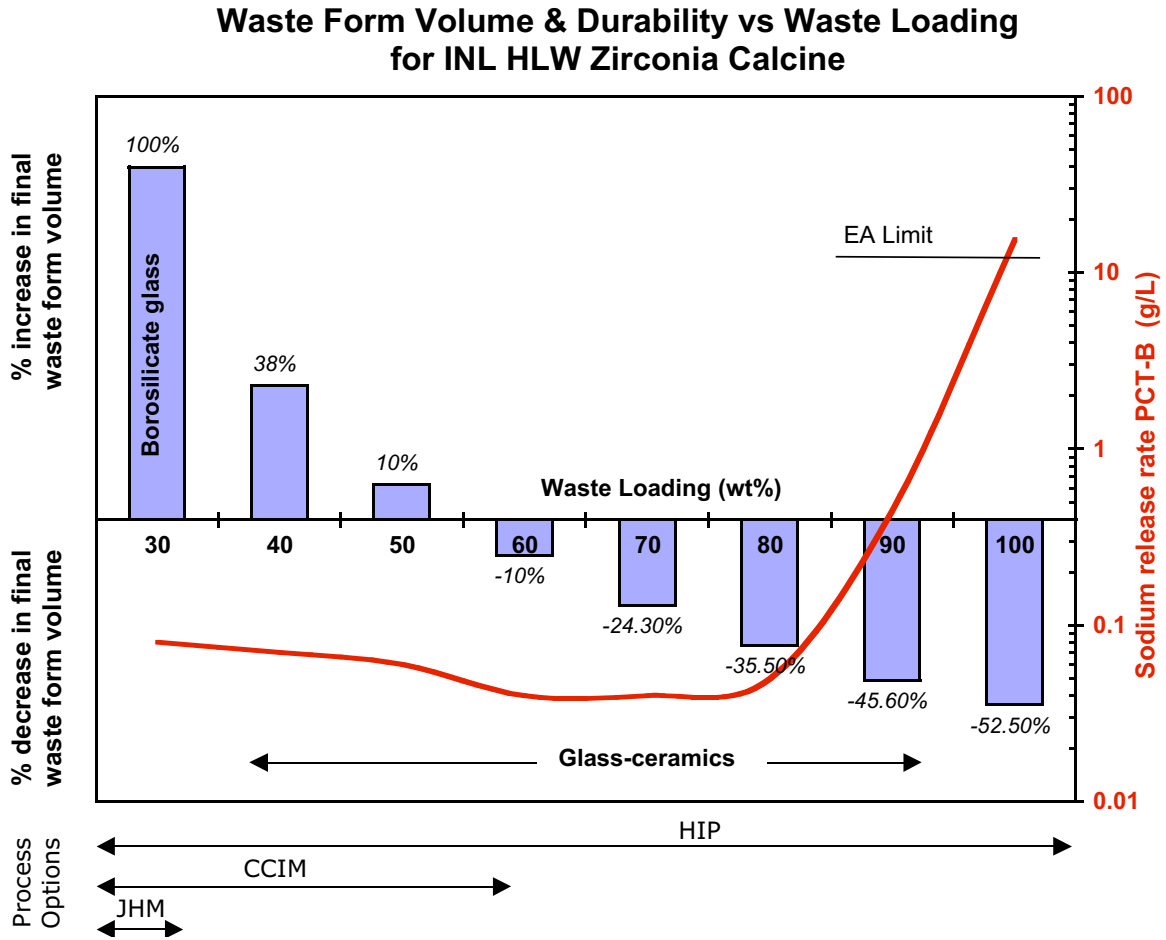


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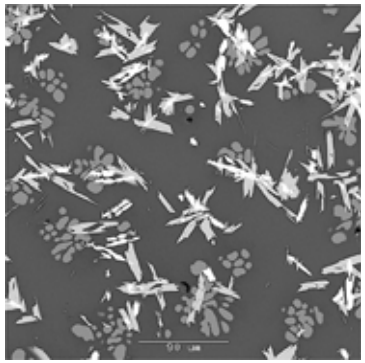
# *CS: High Al and Mixed blend (BS#2)*

30 g
lab melts

Consolidation: CCIM
Cooling: CCC curve
Durability: 10-100 xEA
Waste loading: 51%
Density: 2.79 g/cm$^3$
Crystallization: ~31%

80 kg
pilot melts



<u>Crystalline phases:</u>
zirconolite (major),
fluorite (major),
zirconia (minor)

# CS: High Al and Mixed blend (BS#2)

## Chemical durability PCT-B

| | Normalized concentration (g/l) | | |
|---|---|---|---|
| Element | **PCT-B EA glass Limit** | Cooling from 1300 ˚C @ 300 ˚C/hour | Cooling from 1300 ˚C on 42 h CCC curve |
| Al | | 0.095 | 0.083 |
| B | **16.7** | 0.16 | 0.15 |
| Ca | | 0.067 | 0.053 |
| Cr | | 0.0311 | 0.0317 |
| Cs | | 0.12 | 0.12 |
| Fe | | 0.030 | 0.030 |
| Li | **9.57** | - | - |
| Mg | | 0.087 | 0.096 |
| Mo | | 0.103 | 0.110 |
| Na | **13.4** | 0.097 | 0.083 |
| Nd | | 0.000006 | 0.000033 |
| P | | 0.10 | 0.10 |
| Si | | 0.108 | 0.087 |
| Sr | | 0.052 | 0.049 |
| Ti | | 0.00052 | 0.00052 |
| Zr | | 0.0000047 | 0.000011 |
| F | | 0.057 | 0.053 |

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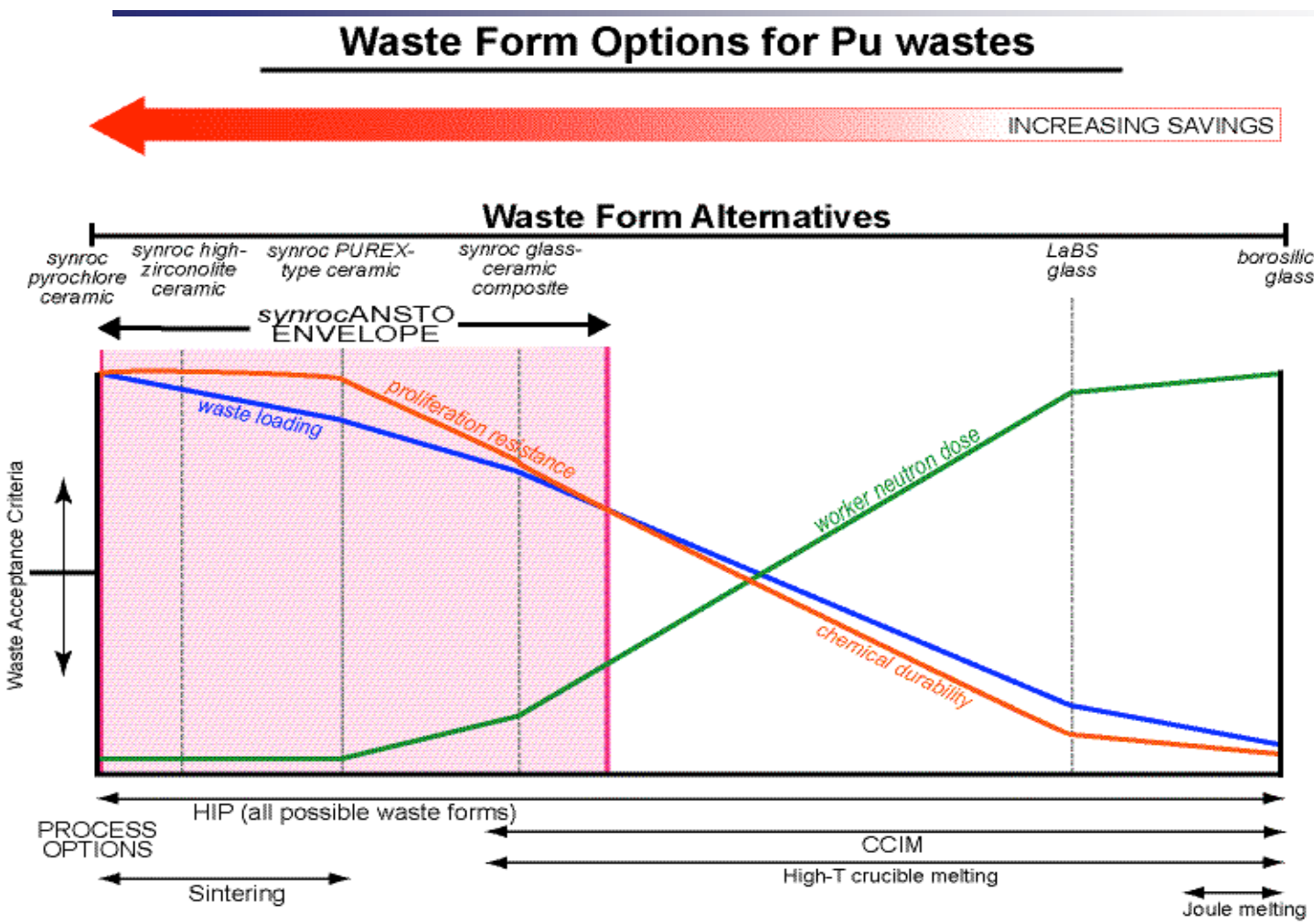
# Plutonium* & Actinide Wastes




**Potential Advantages**

- ✓Proliferation resistant & 100x more chemically durable than glass
- ✓Criticality safe over life-cycle
- ✓8x reduction in neutron dose worker exposure
- ✓Utilize proven nuclear process tech (sinter & HIP)
- ✓Contains >50% more Pu vs glass
- ✓Cost savings

**** '97 DOE shootout report***

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# *CS: PIP project*

## Excess impure weapons Plutonium

| | | |
|---|---|---|
| Consolidation: | Sintering (MOX-like) | High-T Melting |
| Matrix: | ceramic | LaBS glass |
| Actinide loading: | **35%** | **10%** |
| Temp: | 1300°C | 1500°C |
| Durability: | 100-1000 x EA glass | 10 x EA glass |
| Proliferation Resistance: | High | Medium |
| Neutron dose: | low | 8 times higher |
| Criticality control: | life-cycle | during process |

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# *CS: Impure Pu residues in UK*

nexiasolutions
Nuclear expertise intelligently applied

Impure plutonium residues considered intractable due to:

- ✓ Highly chemically and physically heterogeneous
- ✓ Contain impurities problematic for either entirely glass or entirely ceramic waste forms
- ✓ Includes actinides, salts, slags and metals from fuel development work

*synroc*ANSTO Approach - *Glass-Ceramic*

- ✓ Combine the chemical flexibility of glasses with the superior chemical durability and proliferation resistance of synroc ceramics

# *CS: Impure Pu residues in UK*

## *synroc*ANSTO Advantages:

- ✓ Pu partitions in synroc phase over the glass by >100:1.
- ✓ Gd neutron absorbers also readily partition into the zirconolite over glass
- ✓ Excellent chemical durability - normalised Pu releases 10-100x less than borosilicate glass
- ✓ Excellent Pu proliferation resistance, ~20x better than borosilicate glass
- ✓ Flexible process using HIP technology, not sensitive to waste form properties

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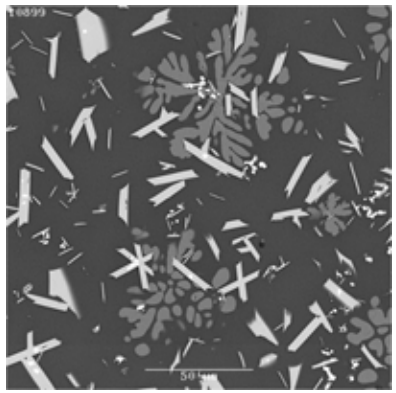
*Nuclear expertise intelligently applied*

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# Niche wastes: Tc, Cs, Sr & I

*synroc*ANSTO has developed a range of waste form solutions that manage the unique risks associated with these waste streams

Advantages of ceramic and glass-ceramic technology for niche waste streams compared to glasses:

- ✓ Elimination of volatility issues, via the use of HIP technology and integration of waste form and process design
- ✓ highly mobile radionuclides are incorporated in durable synroc phases that survive over geological timeframes
- ✓ much higher waste loadings, yet still retain in-built flexibility to feed stream variations, and retain chemical durability
- ✓ thermal stability and ability to endure radiogenic heating over long durations
- ✓ can be easily tailored to different Tc, Cs, and Sr loadings

# Key *synroc*ANSTO Assets

- ✓ *synroc*ANSTO suite of waste forms has become internationally recognized as a defacto performance baseline for alternative waste forms
- ✓ *World class nuclear waste forms scientific team*
- ✓ Extensive and integrated expertise in tailoring the design of ceramic and glass-ceramic waste forms, and complementary process technology, for specific problematic waste streams
- ✓ *25 years continuous experience in developing tailored ceramic and glass-ceramic waste forms*
- ✓ Lower costs and lower risk alternates through deployment via flexible and proven process technologies
- ✓ *Core experienced business and scientific team*
- ✓ Track record of partnering with US DOE labs (via PIP, CRADA, …)

# *synroc*ANSTO Team

| Business Team | Science Team* |
|---|---|
| *Bruce Begg*<br>*Sam Moricca*<br>*Lou Vance*<br>*Arthur Day*<br>*Martin Stewart* | Principal Scientist & Research Leader<br>*Lou Vance*<br>Waste Forms Leader<br>*Bruce Begg*<br>Process Development Leader<br>*Sam Moricca*<br><br>** 32 member team* |

## Related Experience

Core business and scientific team:

- ✓ 25 years waste form experience
- ✓ Integrated waste form with process technology

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# Risks & Mitigation

| | |
|---|---|
| • Waste forms chemistry | *synroc*ANSTO technology internationally recognized as a defacto performance baseline for alternative waste forms |
| • Technology status | Developed waste forms; proven modular process and consolidation equipment |
| • Process Development | Process engineering to tailor waste form to processing scheme to meet objectives |
| • Project Risk | Defined project plan with design, build, install, and operate timelines |
| • Safety | Radiological: Reduced worker exposure and emissions |
| | Industrial: Existing process equipment with established safety and operating procedures |
| | Environment: Reduced worker off-gas emissions & high durability WF for repository |

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# Risks & Mitigation

| | |
|---|---|
| • Business model | Project teaming with waste owner, engineering contractor(s) and ANSTO on incentive waste management basis |
| • Market entry | Processing of problematic HLW, including Pu, where key advantages are significant reductions in total and lifecycle costs and processing schedules; proliferation resistance and reduced worked exposure to neutron dose are demonstrable. |
| • Path to market | Soliciting proposals from/with partners for:<br>• Project opportunities on selected HLW legacy waste stream(s)<br>• Waste form repository acceptance protocols development. |

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# Further Information


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